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Biological Reference Points Based on Sustainability in Harvested Fish Stocks under Changing Productivity Levels

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With 4 Figures and one Table

Abstract

The conditions for commercial harvesting of fish stocks are changing. The traditional fishery management was based on strategies directed at optimising the yield. The relevant biological reference points were F_{MAX} and $F_{0.1}$. The emphasis is now on the sustainability of the exploitation, and the biological reference points are Minimum Biological Acceptable Level (MBAL) and F_{MED}. This study investigates the usefulness of these sustainability reference points when the stock productivity measured in recruitment terms changes, e.g. due to environment variability. The paper shows data from the Eastern Baltic Cod stock where the variability in recruitment has been interpreted as periods with average recruitment productivity and periods with high productivity (yearclasses 1975–1981). The paper concludes that the sustainability reference points MBAL and F_{MED} which are build on the assumption of a time invariant stock recruitment relation are less useful in these situations.

Introduction

The management approach to harvesting fish stocks in the North Atlantic is changing in the mid 1990's from management strategies directed towards optimising the yield often in the short term (HALLIDAY & PINHORN 1996) to place more emphasis on sustainability considerations, see OLIVER et al. (1995) for a discussion of the conservation principles applicable to fisheries management. This is demonstrated by the introduction of the precautionary approach in biological advice on fishery management (FAO 1995). This approach underlines the importance of sustainable exploitation and requires that the biological advices establish a set of upper limits on exploitation. Such upper limits are defined either as maximum fishing mortalities acceptable or as minimum spawning stock biomass. Two such sustainability limits which have been used when providing advice for the management of fish stocks in the North Atlantic are F_{MED} – upper limit allowed on fishing mortality (SISSENWINE & SHEPHERD 1987) and Minimum Biological Acceptable Limit (MBAL) – usually defined as minimum acceptable Spawning Stock Biomass (SERCHUCK & GRAINGER 1992). These limits however are defined under the assumption of a stable population, particularly that an average stock recruitment relation exists and that this relationship remains constant over time. The variability around this relationship is assumed to be random noise. CADDY & MAHON (1995) discuss these and other reference points in more details.

The ICES Advisory Committee on Fishery Management (ACFM) bases at present its advice on the MBAL concept (SERCHUCK & GRAINGER 1992).

However the productivity level of fish stocks changes on a long term scale, e.g. on a 10 year scale or longer. This is best documented for pelagic stocks, e.g. BAUMGARTNER et al. (1992) and for stocks in the Arctic, e.g. for West Greenland cod, see BUCH & HANSEN (1988). Pelagic fish stocks in the Baltic Sea show similar fluctuations, e.g. sprat (APS 1989). Also demersal stocks in temperate waters show fluctuations in their productivity level, e.g. the Gadoid outburst in the North Sea (CUSHING 1984) and cod in the Baltic Sea (KOSIOR & NETZEL 1989; LABLAIKA et al. 1989).

The purpose of this paper is to investigate how two biological reference points (MBAL and F_{MED}) both defined on sustainability considerations would guide the biological advice when applied to fish stocks which change productivity level, e.g. because of environmental changes.

Material and Methods

The analysis presented below is based on the BEVERTON & HOLT (1957) stock-recruitment relationship

Recruitment = A/(1 + B/SSB)

where A is the asymptotic maximum recruitment level and B is the Spawning Stock Biomass (SSB) where the productivity of the stock

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measured in recruitment terms is half of the maximum level. Actual data show a significant noise level around this mean recruitment.

The Minimum Biological Acceptable Level (MBAL) is defined as the minimum Spawning Stock Biomass (SSB) above which recruitment is independent of SSB. In terms of the extended BEVERTON & HOLT stock recruitment model this means that 1) Recruitment is close to A and 2) deviations from this relationship are random noise without auto-correlation between years. This may be formulated, if the minimum average recruitment level acceptable is $\alpha\%$ (<100%) of the asymptotic value, as

Recruitment > α *A

or

SSB > $\alpha/(100 - \alpha)$ *B = MBAL

This calculation is however difficult to apply because the BEVERTON & HOLT stock recruitment model as other stock recruitment models do not fit the data well. The model is however used here to illustrate some principle problems with the sustainability biological reference points.

This MBAL sustainability criteria may be reformulated as an upper limit on the fishing mortality calculated from an equilibrium Yield per Recruit model. On that basis the reference fishing mortali-

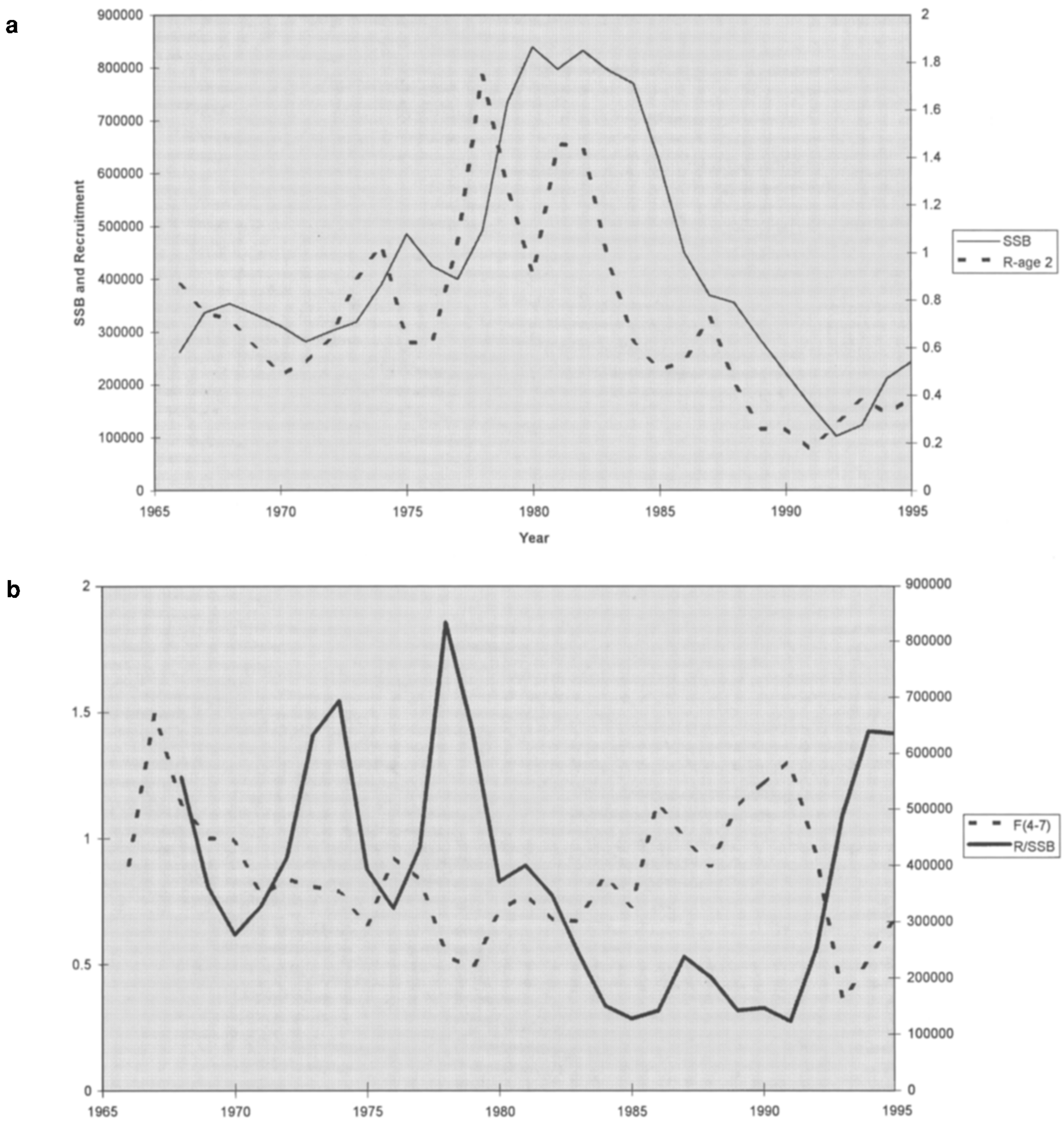

Fig. 1. Development of the Eastern Baltic Cod 1966–1995. – **a.** Spawning Stock Biomass (SSB) and recruitment (age 2 years); **b.** Fishing mortality and recruits per SSB unit (average over age groups 4–7).

ty is a maximum acceptable level if the stock is on average to reproduce itself. Such levels must therefore be considered as minimum/maximum limits which should not be exceeded and not as targets. If fishing mortality is kept at or below F_{MED} the spawning stock biomass will on average be kept at or above a level at which historically the stock has been able to reproduce itself. F_{MED} can be overestimated, and therefore misleading, in cases where exploitation has been high and the recruitment of the stock low for a large part of the time series used for the calculation of F_{MED}. F_{MED} is calculated by averaging the SSB/R ratio and based on a SSB/R vs. Fishing mortality graphs estimate the corresponding fishing mortality (SISSENWINE & SHEPHERD 1987).

Data for the Eastern Baltic Cod stock were taken from the fish stock assessments produced by the relevant ICES Working Group, ICES 1996. Fig. 1a shows the development of the Spawning Stock Biomass and recruitment (age 2 years) for the period 1966–1995 and Fig. 1b shows the R/SSB ratio and fishing mortality (average age 4–7 years). Fig. 2 shows the stock recruitment diagram for the yearclasses 1968–1993.

The simulations presented in the results are based on population dynamic parameters (natural mortality, exploitation pattern, average individual weights by age group and the proportion mature by age group) taken from the those pertinent to Eastern Baltic Cod, ICES (1996). The study is based on the parameters of the BEVERTON & HOLT relation which was taken as A = 1000 and B = 150. The corresponding equilibrium SSB is slightly below 1600 or B/SSB < 0.1. Even setting α = 90% in the definition of MBAL in the above equation (a very conservative limit) will make the equilibrium population above MBAL.

Results

Fig. 1a illustrates the period with high recruitment in the late 1970s – early 1980s. The figure also shows that the spawning stock biomass lacks behind the recruitment outburst suggesting that the productivity of the Eastern Baltic Cod stock increased rather than a stock recruitment relation was in effect. This is also seen from the R/SSB ratio shown on Fig. 1b. Fig. 2 showing the stock recruitment relation for the yearclasses 1968–1993 indicates that the recruitment level during the Baltic outburst (yearclasses 1975–1981) was about twice that of the rest of the data. The period with high recruitment productivity was also a period with high SSB and the data show no indications of where a MBAL might be for this high productivity period.

Fig. 3 shows the development of the Recruit/SSB ratio under the assumption of two changes 1) A is halved but B remains unchanged between year 3 and 4 and 2) A and B are both halved. It is seen that the theoretical curves do not differ very much whether the B parameter in the BEVERTON & HOLT stock recruitment relation, i.e. MBAL changes or not. It is also seen that the change in the R/SSB ratio is a sudden burst which levels out after some few years. This is seen both in the situation when the MBAL does not decrease and when the MBAL level is dropped by a factor of 3. The implication for calculation of F_{MED} is that this value will not reflect the change in MBAL.

Interpreting the corresponding graph for Eastern Baltic Cod (Fig. 1) in the light of this theoretical exercise, we find a significant drop in R/SSB 1979–1984 but also that the R/SSB ratio increases after 1991. Fig. 1b shows that the fishing mortality 1979–1991 actually was increasing during the period. This would in the model suggest an increase in the recruitment/SSB ratio as long as the SSB is above MBAL. In the Eastern Baltic Cod stock both SSB an recruitment decreased during this period, see Fig. 1a. The F_{MED} values are shown in Table 1.

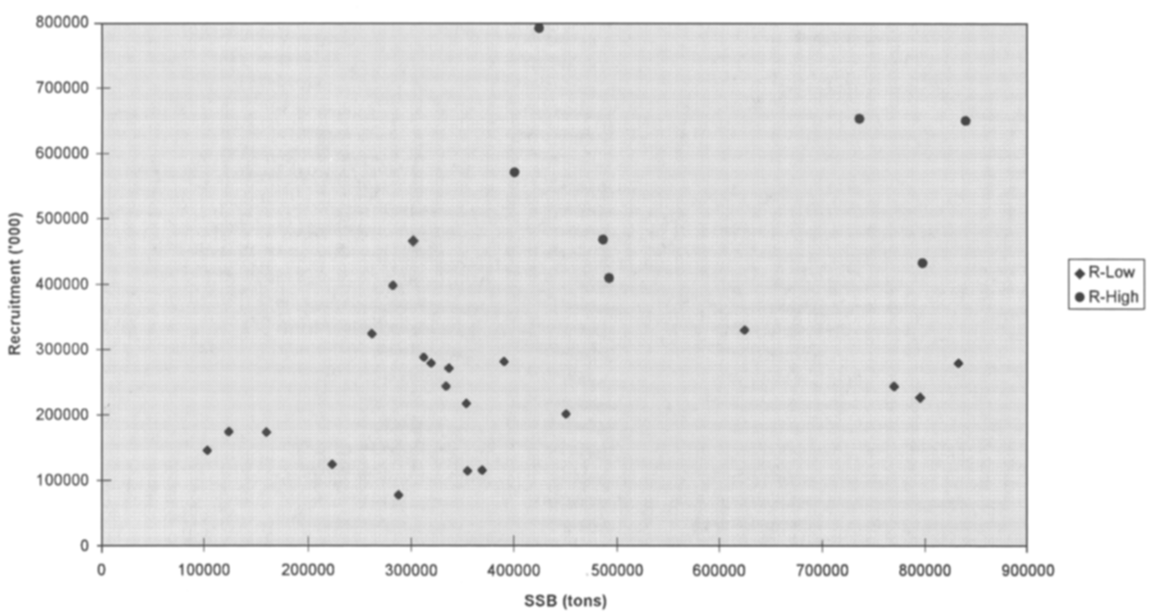

Fig. 2. Stock recruitment diagram for the yearclasses 1968–1993 of the Eastern Baltic Cod. The yearclasses with high productivity (1975–1881) are shown as R-High.

The simulations are for a situation when the changes in productivity do not bring the stock on average below the B level as discussed in "Material and Methods". The MBAL should be set substantially above this level. The two curves for B = 300 and B = 50 approach almost the same asymptote for R/SSB which means that the F_{MED} is the same for the two situations and also independent of the absolute level of recruitment. The differences found above depend on the number of years with high and low productivity in the data series. The estimate of F_{MED} depends on the number of years with changing productivity seen in the data.

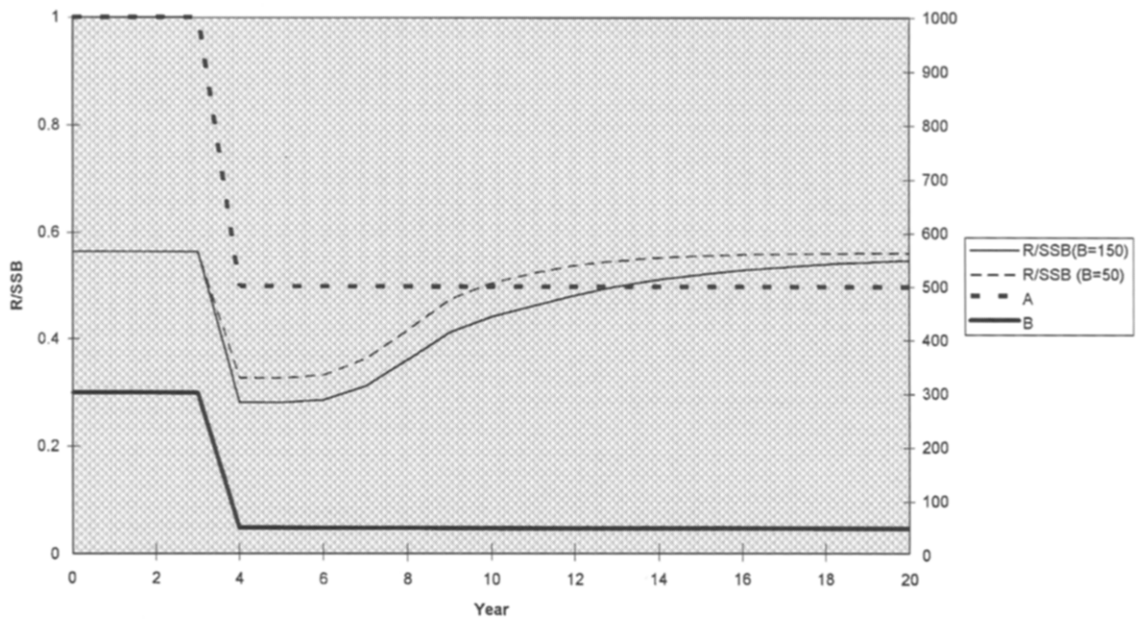

Fig. 3. Theoretical development of the Recruitment/Spawning Stock Biomass (R/SSB) ratio from changes in the stock-recruitment relationship. The figure shows the changes in the ratio when 1) only the level of recruitment A is halved but the MBAL level (B) remains unchanged and 2) when also the MBAL decreases (B is divided by 3).

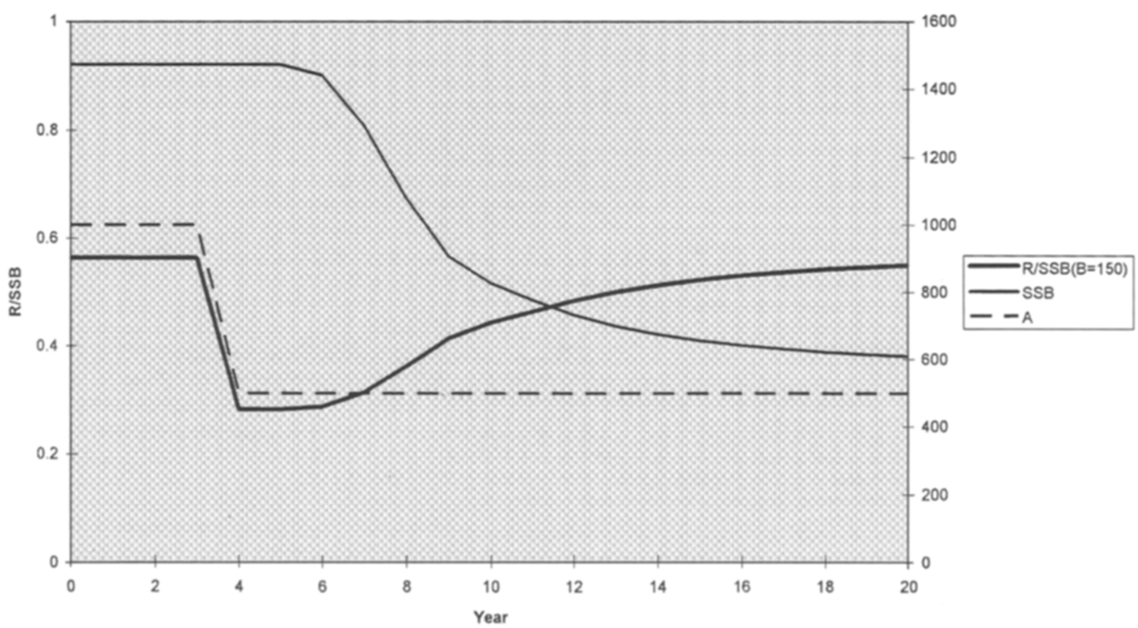

Fig. 4. Theoretical development of the Recruitment/Spawning Stock Biomass (R/SSB) ratio from change in the stock-recruitment relationship. The level of recruitment A is halved but the MBAL level (B) remains unchanged. The drop in the SSB is seen to correspond to the increase in R/SSB ratio after the initial drop.

Table 1. F_{MED}-values.

	Equilibrium high production level	20 year mean with drop in productivity but unchanged MBAL between year 3 and 4	20 year mean with drop in productivity and MBAL between year 3 and 4
A	1000	500	500
B	300	300	50
Average SSB/R	1.77	2.14	1.99
Equilibrium SSB	1473	609	837
F_{MED}	0.69	0.56	0.61

Discussion

Fish stocks exhibit variation in recruitment between years but also show shifts in productivity levels which are longer lasting, e.g. the Gadoid outburst in the North Sea (CUSHING 1984) or the corresponding event in the Baltic Sea Cod for the yearclasses 1975–1981.

The simulations presented above illustrate that the biological reference points based in stock-recruitment relations are difficult to apply for stocks which change recruitment productivity. The estimated F_{MED} value will drop corresponding to a decrease in productivity although the equilibrium F_{MED} under the changed regime would establish itself at the same level as before. The estimated F_{MED} will show variability with the length of the data series. So the estimated F_{MED} appears more uncertain than it actually is. However the behaviour is in correspondence with a cautious approach to fisheries, the productivity situation appears to be declining and the management advice will be to decrease fishing. Because of the decline in stock caused by the reduction in productivity the yield will actually decrease and the reference point used may actually increase hardship on the fishing industry.

MBAL is most often established based on inspection of the stock-recruitment diagram without a rigorous calculation procedure. ICES (1996) indicates that MBAL is very difficult to establish for Eastern Baltic Cod. The level suggested is 400–500,000 tons of spawning biomass. The estimated level of SSB has since about 1987 been below that value. In the light of the discussion above estimation of F_{MED} becomes particularly problematic in this situation.

Both the MBAL and the F_{MED} reference points are related to a stock-recruitment relationship. Such relationships are usually poorly known if they exist at all except for stocks at extremely low SSB levels. This uncertainty corresponds to an equal large uncertainty in the biological reference points based on fishing mortality. The Eastern Baltic Cod, Fig. 2, presents an example of the scatter often seen.

Our aim is to maintain the productivity of the fish stocks in the longer time perspective e.g. for centuries. There is substantial variability in the productivity of the fish stocks with longer frequencies than yearly as used in most simulation models. This variability is best documented for pelagic fish stocks, see e.g. KAWASAKI & OMORI (1988), BAUMGARTNER et al. (1992) but is also seen in Cod by CUSHING (1984), BUCH & HANSEN (1988) and LARRAÑETA (1988). Also flatfish seems to show a similar variability in productivity, e.g. American Plaice (BOWERING et al. 1996). It is however not only the recruitment which varies in a fish stock. Growth shows some variability, see BRANDER (1995) for a discussion of growth variability of Atlantic Cod. We are however constrained in our efforts since we only have 20–30 years of data on which the biological advice is based. To include the desired longer time span in our considerations we must rely on theoretical considerations best to extrapolate more realistic the existing data to this longer time perspective. These models have mostly been build on equilibrium considerations not taking the inherent variability in stock productivity into account. Therefore models which are not based on stability of productivity are necessary.

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